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THE RELATIVE SOLUBILITIES OF THE CHEMICAL CONSTITUENTS OF ROCKS

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Several years ago, while making an estimate of the rate of chemical denudation, which, from skepticism in regard to the trustworthiness of the available data, was never offered for publication, the writer was impressed with the desirability of determining, so far as might be possible, the average relative rates at which the predominant chemical constituents of rocks were taken into solution in drainage waters. So far as could be learned at the time, the problem had never been definitely formulated on a quantitative basis, nor its solution in numerical terms attempted.

The writer's aim was to obtain definite numbers which should express the relative rates at which the common oxides are dissolved by natural waters, using the oxides in the ordinary conventional sense in which they are considered as rock components. To be more explicit, the actual minerals, of which rocks are made up, were not considered at all but merely the ultimate chemical composition of rocks, expressed in terms of oxides. While the method pursued gave results suggesting interesting possibilities, it was felt that, as in the case of the problem of chemical denudation, the data available were not sufficiently trustworthy to warrant publication. At present, however, more reliable data are at hand

and, though still defective in certain respects, they afford the needed basis for a preliminary discussion of the problem.

At the outset, it should be made clear in what sense the term "relative solubilities" is used. Probably, all but the simplest minerals, when acted upon by water, do not merely dissolve, in the strict physical sense of the word, but decompose,[1] so that the constituents appear in the solution in quite different proportions from those in which they are present in the mineral. As rocks are mixtures of minerals, it is obvious that, when they are acted upon by water, there must be a very complex series of decompositions and interactions. With the details of these operations, the present inquiry is not concerned, but merely with their final results as represented by the materials in solution, derived from the rocks. For this purpose, the latter are regarded as composed, not of minerals, but of oxides, as ordinarily expressed in the results of chemical analysis. Such a conception of the rocks requires, of course, no apology, as it is necessary, and universally used, in dealing with them from the chemical point of view.

Thus, by the term relative solubilities, as here used, is meant the relative amounts of the elements, as oxides, abstracted from the rocks of the crust, by drainage waters, as compared with the amounts of the same oxides in the rocks. Obviously, this use of the word solubility is quite different from the strict sense, where a solution acts upon a homogeneous substance, without decomposition, but no other term expresses the idea as well, and such a usage is so familiar to geologists as to justify it in the present connection. A similar plea may be made for considering the oxides, the "chemical constituents" of rocks, as distinguished from the actual minerals. As before stated, these oxides are continually made the chemical units in the discussions of rocks, and this well-established custom necessitates, in the present discussion, the expression of water analyses in oxides rather than ions, as is the current custom. The use of ions for both classes of analyses would lead to the same results, but would, of course, be highly artificial, as well as unfamiliar, in the case of rocks.

[1] Cf. A. S. Cushman, and P. Hubbard, *The Decomposition of the Feldspars*, U.S. Department of Agriculture, Office of Public Roads, Bull. No. 28, p. 10, 1907.

That the constituents of rocks and minerals differ widely in their solubility is a familiar fact, made apparent by a superficial examination of rocks in the field, and emphasized by laboratory experiments, and the analysis of fresh and weathered rocks and of natural waters. As a result of investigations along these lines, it is well known that certain oxides, such as silica and alumina, are relatively resistant, while others, such as the alkalies and alkaline earths, pass somewhat readily into solution. Thus, orthoclase yields its alkalies in solution, while the silica and alumina remain in the solid state as kaolinite and quartz.

For our present purpose, this may be expressed simply as due to the greater solubility of the alkalies as compared with silica and alumina, ignoring the obvious fact that it is, in reality, a case of decomposition, not simple solution. It need hardly be said that the solubility (as the term is here used) of an oxide varies greatly with the compound in which it occurs, but the results of all such variations enter into the average relative solubility, as here discussed, without demanding any separate treatment.

Quantitative data in regard to solubilities are generally obtained by one of two very different methods. A definite amount of the rock or mineral is treated with a definite amount of water, the conditions varying with different experiments, and, by analysis of the resultant solutions, the relative amounts of the constituents dissolved are determined. This method is artificial, but, by a proper adjustment of the conditions of the experiment, may yield results of importance in interpreting natural phenomena.[1] The second method of acquiring quantitative data is to analyze fresh rocks or minerals and the corresponding residual clays or alteration products and, by a comparison of the results, to deduce the amounts of various constituents removed in solution. The first method has, thus far, been applied chiefly to minerals, but the second has been extensively applied to rocks, and has yielded results of great interest.

The two methods of investigation are essentially distinct and, while they supplement each other, do not yield strictly comparable results. In the first, or laboratory, method, a definite amount of the solid is treated with a definite amount of the solvent, equilibrium is established, and there is no further change of composition of either solid or solution. In nature, on the other hand, there is a continued renewal of the solvent, so that, while the most soluble constituents are first removed in relatively large quantities, the others must yield ultimately to repeated attack and the amount finally dissolved depends upon the length of time during which the process continues. Thus, to yield comparable results, the laboratory sample would have to be treated repeatedly with fresh supplies of solvent. However, this applies more especially to chemical weathering where residual clays accumulate to considerable depth and lie a long time. When secular elevation and erosion bring fresh rock within the range of solvent action, there is a tendency to compensate somewhat for the fresh supplies of solvent continually furnished, and thus to bring the conditions more nearly into harmony with those of the laboratory experiment. But an even closer approximation to the laboratory method is obtained if the entire mass of the crust traversed by meteoric waters is considered as a unit acted upon by the total body of drainage waters which, falling relatively pure upon the land areas, immediately begin to exert their solvent power and, ultimately, carry to the sea the different constituents of the crust, in varying amounts.

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[1] Cf. W. P. Headden, "Significance of Silicic Acid in Waters of Mountain Streams," *Am. Jour. Sci.* (4) XVI (1903), 169–184.

It was from this point of view that the problem was approached, when first considered, the composition of the crust and of the drainage waters being the basis of calculation. The former was afforded by Clarke's[1] familiar estimates of the composition of the outer shell of the crust and of the sedimentary rocks. Of the average composition of the drainage waters, only Sir John Murray's[2] preliminary estimate was available, and it was because of serious doubt as to the accuracy of these figures that publication of the results was abandoned.

While there is still much to be wished for in regard to data bearing upon the composition of drainage waters, the last few years have afforded sufficient added information in this direction to warrant renewed consideration of the problem.

[1] F. W. Clarke, *Bull. U.S. Geol. Surv.*, *228*, p. 19.

[2] Sir John Murray, *Scottish Geog. Mag.* (1887), p. 76.

In the present paper, the essential data used are Clarke's later estimates of the composition of the crust, and the same author's estimated mean composition of river waters.[1] The results obtained from these data are supplemented by data from other sources, as shown below.

ABUNDANT CONSTITUENTS OF ROCKS DISSOLVED IN RIVER WATERS (RECALCULATED TO 100)

	Clarke's Mean for Rivers of the Earth*	Mississippi River†	Ottawa River‡	Cache à la Poudre (Colo.)§	Feldspar Solution¶
CaO	48.34	51.05	37.12	31.12	14.43
Na_2O	14.61	16.45	9.73	21.48	7.39
MgO	9.55	15.86	12.57	7.22	1.08
K_2O	3.09	3.44	3.02	4.89	15.45
SiO_2	19.76	12.52	31.97	34.64	57.41
R_2O_3	4.65	0.68	5.59	0.65	4.24
	100.00	100.00	100.00	100.00	100.00

* Clarke's mean for the abundant constituents of the rivers of the earth.
† Mississippi River water, with Na_2O and K_2O calculated at the ratio of 4.24 to 1. Analysis by J. L. Porter. Annual average of Dole and Stabler as quoted by Clarke, *op. cit.*, p. 3.
‡ Ottawa River. Analysis by F. T. Shutt, published by R. A. Daly.
§ Cache à la Poudre, Colorado, Analysis by W. P. Headden.
¶ Feldspar Solution. Analysis by W. P. Headden.

The above constituents were recalculated to 100 per cent in order that their relative amounts in the different waters might be readily compared. For the rock analyses this was unnecessary, as the abundant constituents predominate so markedly that their amounts would be little changed by such recalculations, while, for determining the relative solubilities, it is not needed.

ABUNDANT CONSTITUENTS OF ROCKS

	Igneous Rocks*	Sediments†	Lithosphere‡	Surface Rocks§	Pike's Peak Granite¶	Feldspar**
CaO	4.81	5.42	4.82	5.27	0.74	0.314
Na_2O	3.41	1.12	3.28	1.69	3.10	2.728
MgO	3.89	2.52	3.98	2.86	.07	0.029
K_2O	2.95	2.80	2.96	2.84	5.92	11.592
SiO_2	59.99	58.51	59.79	58.88	74.90	65.760
R_2O_3	21.34	18.69	21.25	19.35	14.48	19.291

* Abundant Constituents in Clarke's estimated average Igneous Rock, *Op. Cit.*, p. 13.
† Abundant Constituents in Clarke's estimated average Sediment, *Ibid.*
‡ Abundant Constituents in Clarke's estimated average Lithosphere, *U.S. Geol. Surv. Bull. 330*. p. 31.
§ Estimated composition of "Surface Rocks," derived by combining Igneous Rocks and Sediments in the ratio of one to three.
¶ Average of Analyses of four granites from Pike's Peak Quadrangle by W. F. Hillebrand, *Journal of Geology*, VIII, 237.
** Analysis of Feldspar, Horsetooth, Col. by W. P. Headden, *op. cit.*, p. 181.

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[1] F. W. Clarke, *A Preliminary Study of Chemical Denudation*, Smithsonian Coll., Vol. LVI, No. 5, p. 8, 1910.

Were the various constituents of rocks equally susceptible to the action of drainage waters, they would be carried to the sea in the proportions in which they occur in the crust. That this is far from being the case is a most familiar fact, and it is evident that they go into solution at very different rates. These rates are expressed by the ratios between the amounts of the various constituents in the rocks and in the drainage waters, respectively. That these relative rates must vary widely in different cases there can, of course, be no doubt, but the average rates are simply determined by the comparison of the compositions of the surface rocks and of the drainage waters. For the latter, Clarke's "General Mean"[1] is taken, column I, using, as in all other cases, only those constituents that are abundant in rocks.

For the rocks, the simplest method is to take Clarke's average composition of the lithosphere,[2] but this introduces an obvious source of error. This average represents a shell ten miles thick, of which probably 95 per cent consists of igneous rock. Drainage waters, being relatively superficial, exert their influence on rocks that are probably 75 per cent sedimentary and have lost certain constituents, particularly sodium, now held in solution in the sea. For this reason, it is necessary to use, as the basis of calculation, figures that allow for this permanently dissolved material. Moreover, in so far as the elements in sediments are combined differently from what they were in the crystalline rocks, their relative solubilities are doubtless affected. Correct results are to be obtained only by comparing the composition of river waters with that of the actual materials of their basins, and in the absence of precise data, the closest approximation possible must be sought.

This has been done by taking Clarke's "weighted mean"[3] of the composition of sedimentary rocks and his estimate of the composition of igneous rocks[4] and combining them in the ratios of three to one, in accord with Von Tillo's estimate of the relative areas of sedimentary and igneous rocks, the results appearing in column II and called "surface rocks." These figures are assumed to represent the composition of the rocks leached by drainage waters, and, compared with the mean composition of the latter, column I, give the average relative solubilities of the abundant constituents of the earth's crust.

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[1] *Op. cit.*, p. 8.

[2] "The Data of Geochemistry," *U.S. Geol. Surv. Bull., No. 330*, p. 31.

[3] F. W. Clarke, *A Preliminary Study of Chemical Denudation*, Smithsonian Misc. Coll., Vol. LVI, No. 5, p. 13, 1910.

[4] *Loc. cit.*

The latter values are represented by the ratios between the constituents in the water and the corresponding constituents in the rocks. These values appear in columns III and IV, in the latter recalculated to a basis of lime = 100, lime having the highest relative solubility, being an abundant constituent, and readily determined with accuracy.

The constituents are written in the order of relative solubility beginning with CaO.

	I Clarke's Mean River Water	II Surface Rocks	III Rel. Solubilities	IV Rel. Solubilities (CaO = 100)
CaO	48.34	5.27	9.17	100.0
Na_2O	14.61	1.69	8.64	96.1
MgO	9.55	2.86	3.34	36.3
K_2O	3.09	2.84	1.09	11.9
SiO_2	19.76	58.88	0.34	3.7
R_2O_3	4.65	19.35	0.24	2.6

Thus, assuming the accuracy of the figures in columns I and II, it follows that the abundant oxides of the crust are dissolved at relative rates represented by the figures of columns III and IV. Lime and soda appear to be dissolved at about the same rate, magnesia at about one-third this rate, potassa again about one-third as fast as magnesia, silica about a third as fast as potassa, and the sesquioxides about two-thirds as fast as silica. How far these figures may be trusted depends, obviously, upon the reliability of the estimated composition of river waters and of surface rocks. That these estimates will be modified in future is beyond question, and any change will, of course, affect the values of the relative solubilities. But it is believed that the figures given are a fairly close approximation to the true values, indicating, at least, the proper orders of magnitude. The most questionable figure is that for soda, since it is this constituent that is largely retained in the ocean and least likely to be accurately estimated in sediments, where the number of analyses is limited. The other constituents cannot differ much in relative amounts in sediments and in igneous rocks. Van Hise[1] has pointed out, and explained, certain discrepancies when the analyses of the sediments are compared with those of the igneous rocks, but for the present purpose these may be overlooked. However, in view of the possible divergence of the compositions of sediments used from the true mean, it may be worth while to make a similar calculation using the composition of the igneous rocks, instead of that of the surface rocks, as above estimated. It is probable that this composition of the igneous rocks is more accurate than that of the sediments which was introduced in calculating the composition of the surface rocks, and, except for the soda, fairly accordant results might be expected, although as pointed out above, the surface rocks must differ from igneous rocks not only in bulk composition but also as to compounds present, and a comparison of the composition of drainage waters with that of the igneous rocks is, therefore, highly artificial. The results of such a comparison of the mean composition of river waters with that of the average composition of igneous rocks, are as follows:

	V Clarke's Mean River Water	VI Igneous Rocks	VII Solubilities	VIII Solubilities ($CaO = 100$)
CaO	48.34	4.81	10.05	100.00
Na_2O	14.61	3.41	4.28	42.5
MgO	9.55	3.89	2.46	24.5
K_2O	3.09	2.95	1.05	10.4
SiO_2	19.76	59.99	0.33	3.3
R_2O_3	4.65	21.34	0.22	2.0

Comparing the figures of columns VII and VIII with the corresponding figures of columns III and IV, the expected relations are seen, substantial agreement except for soda which shows, in column VII and VIII, decidedly smaller relative solubility. This must necessarily be the case, since the river waters actually derive their soda largely from the already depleted sediments, and if, as here done, their content be compared with that of the unleached igneous rocks, a much lower, and essentially abnormal relative solubility must be obtained. While there is a tendency in the same direction for MgO, it is too slight to account for the lower figure. The fairly good agreement of the other constituents is an argument in favor of the essential reliability of the data used for the calculation, and gives added confidence in the relative solubilities of columns III and IV.

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[1] C. R. Van Hise, "Treatise on Metamorphism," *Monograph* XLVII, *U.S. Geol. Surv.* (1904), chap. xi.

It is evident that, on the basis of solubility, the constituents fall into four distinct groups; lime and soda, magnesia and potassa, and silica and sesquioxides, although potassa might be classed with the last two, making only three groups.

It is unfortunate that alumina and iron oxide cannot be estimated separately, particularly with reference to the history of the sedimentary iron ores, but in the analyses of river waters used as the basis of calculation, they are determined together and, thus, cannot be separated here. Furthermore, these constituents occur in small quantity in waters, are difficult to determine accurately and, therefore, even when taken together, their relative solubility is open to question, although its order of magnitude is clearly fixed.

The figures of columns III and IV, then, in so far as they are accurate, express a most general relation existing between the chief chemical constituents of rocks with reference to their behavior under the solvent action of drainage waters. Based, as they are, upon analyses of the present surface rocks and existing rivers, they hold good only for existing conditions: petrologic, topographic, and climatic. A marked change of any of these conditions would produce a corresponding change in the relative solubilities, and there can be no doubt that many such changes have occurred. Doubtless, on the average, the divergence from existing values was greatest in the most remote geological times, and this must be taken into account in all considerations of chemical denudation in earlier periods. However, it is obvious that the intervals between the solubilities of the four groups are of such magnitude as to allow of considerable range, without changing the order, so much so as to make it not unlikely that the order has been the same throughout geological time.

This order, it may be noted, is in general agreement with the order of amounts dissolved derived from the study of weathering and its solid products, as shown by Merrill,[1] Van Hise[2] and others, although that method gives no numerical relation, and its generalizations are commonly based chiefly upon igneous rocks. Van Hise calls attention to the fact that the different constituents are removed in surprisingly similar amounts, but this, of course, concerns the end result, and takes no account of relative rates of solution. As pointed out earlier, the more soluble constituents go first, so there is an ever-present tendency toward the relative concentration of the constituents of low solubilities, silica and the sesquioxides and, to a less degree, potash, in the residual clays. Were there no mechanical erosion a certain kind of equilibrium might be reached, in which residual clays would have practically uniform compositions (varying with climatic conditions) not changing with further solution. That there is a tendency to such a condition is emphasized by a comparison of the composition of residual clays, showing as they do, striking resemblances, with the widely divergent composition of rocks.

It is believed that the above figures for relative solubilities are of sufficient interest in themselves to warrant their publication, while they touch upon many problems in connection with weathering, chemical denudation, metamorphism, etc. Even upon so large a theoretical question as the composition and density of continental and oceanic areas, as discussed by Chamberlin and Salisbury,[3] they have a bearing.

While it is true that the relative solubilities given above express only a most general relation, and cannot be applied to a specific case, the simple method of comparison can be used, wherever the necessary data are available, with instructive results. From the widely varying compositions of streams and of the rocks of their drainage basins, it is clear that most divergent results must be obtained. It is only as the conditions approach the average for the entire land area that any close approximation to the mean solubilities may be expected. A few cases are appended by way of illustration.

[1] G. P. Merrill, *Rocks, Rock Weathering and Soils* (1906), p. 220.

[2] C. R. Van Hise, *op. cit.*

[3] *Geology*, II, 107.

The composition of the Mississippi River water, so far as the abundant oxides are concerned and with the soda and potassa calculated according to Clarke's[1] ratio, is given in IX, calculated to 100 from Dole and Stabler's analysis. Clarke's[2] average composition of sediments is assumed to represent the composition of the Mississippi basin. The resulting relative solubilities appear in columns XI and XII:

	IX Mississippi River	X Average Sediments	XI Solubilities	XII Solubilities ($CaO = 100$)
CaO	51.05	5.42	9.6	100.0
Na_2O	16.45	1.12	14.7	152.8
MgO	15.86	2.52	6.3	65.5
K_2O	3.44	2.80	1.2	12.5
SiO_2	12.52	58.51	.214	2.2
R_2O_3	0.68	18.69	.036	0.4

Compared with the figures of column VIII, there is a striking increase in the solubility of soda and magnesia. In other words, these two constituents are notably abundant in Mississippi water as compared with the amounts in the rocks, if these latter are accurately represented by the analyses used. If they are too low in the estimate used, the solubilities would come nearer the mean values. Potassa and silica are in fair accord with the mean, while the sesquioxides are low. On the whole, however, the agreement is surprisingly close in view of the fact that a single river basin is concerned, even though it be of a rather generalized type.

Another case, representing quite different conditions, is afforded by the Ottawa River, draining an area of crystalline rocks. The composition of the dissolved salts, as given by Daly[3] and recalculated to 100 per cent of abundant oxides, is shown in column XIII.

Clarke's[4] estimate of the mean composition of the lithosphere is taken to represent the composition of the Ottawa's drainage basin, column XIV, although the assumption is recognized as a rather sweeping one.

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[1] *Op. cit.*, p. 9.

[2] *Op. cit.*, p. 13.

[3] R. A. Daly, "First Calcareous Fossils and the Evolution of Limestones," *Bull. Geol. Soc. Am.*, XX (1909), 158.

[4] "The Data of Geochemistry," *U. S. Geol. Surv. Bull., No. 330*, p. 31.

The resultant relative solubilities are given in columns XV and XVI.

	XIII Ottawa River	XIV Average Crust	XV Solubilities	XVI Solubilities (CaO=100)
CaO.........	37.12	4.82	7.70	100.
Na_2O........	9.73	3.28	2.96	38.5
MgO.........	12.57	3.98	3.16	40.1
K_2O.........	3.02	2.96	1.02	13.4
SiO_2.........	31.97	59.79	.53	6.9
R_2O_3.........	5.59	21.25	.26	3.4

These figures approach most closely to those derived from comparison of the mean river water with the average igneous rocks, and differ most widely from those derived from the Mississippi River and average sediments.

The most striking variation is in the soda, which, instead of being close to lime in solubility, falls below, but close to, magnesia, thus changing the solubility groups. It is interesting to note that this order of relative solubility is the same as the order of percentage loss for each constituent for a group of nine crystalline rocks, as given by Van Hise.[1]

It would seem to be a necessary inference that, on the average, the silicates of the alkaline earths and sodium are more readily decomposed than those of potassium, aluminum and iron.

Without placing too much dependence upon either case, it seems safe to conclude that the figures for the Ottawa River roughly represent the relative solubilities for crystalline regions, while those for the Mississippi roughly represent the relative solubilities for sedimentary regions.

It is rather surprising to find the relative solubilities of soda and magnesia greater in sediments than in crystallines. While this may be due in part to the presence of more soluble compounds the essential reason probably is afforded by the rule elsewhere pointed out that, as a constituent decreases in absolute quantity in the rocks, its relative solubility increases.

The average of the solubilities derived from the Mississippi and the Ottawa is given in column XVII and the weighted mean, taking the values for the Mississippi and the Ottawa in the ratio of three to one, is given in column XVIII.

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[1] *Op. cit.*, p. 516.

	XVII	XVIII
CaO	100.0	100.0
Na_2O	95.6	124.2
MgO	52.8	59.1
K_2O	12.9	12.7
SiO_2	4.5	3.4
R_2O_3	1.9	1.1

Representing roughly the relative areas of crystalline and sedimentary rocks, the figures in column XVIII must be compared with those of IV.

The same groups appear in column XVIII, but owing to the high figure obtained for soda in the Mississippi water this constituent has changed places with lime as most soluble, while, for a similar reason, magnesia gives an abnormally high figure. Nevertheless, when the nature of the data used is considered, the agreement between these special cases and the general case is as close as could be expected.

What widely different relative solubilities may prevail in an individual case, which does not approximate to the general conditions, is shown by the waters of the Cache à la Poudre of Colorado, as analyzed by Headden[1] when compared with the average of four granites, from Pike's Peak Region, analyzed by Hillebrand,[2] which may be taken as fairly representing the stream basin.

	XIX Cache à la Poudre	XX Pike's Peak Granite	XXI Solubilities	XXII Solubilities ($CaO=100$)
CaO	31.12	0.74	42.05	100.0
Na_2O	21.48	3.10	6.91	16.4
MgO	7.22	0.07	103.14	244.4
K_2O	4.89	5.92	0.84	2.0
SiO_2	34.64	74.90	0.49	1.0
R_2O_3	0.65	14.48	0.05	0.1

A mere glance at the two analyses (XIX and XX) shows a notably high content of lime and magnesia in the water as compared with the composition of the granite, and this is accentuated by the figures for relative solubilities (XXI and XXII).

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[1] *Loc. cit.*

[2] E. B. Mathews, "Granite Rocks of the Pike's Peak Quadrangle," *Journal of Geology*, VIII, 237.

Even the groups have been changed, and magnesia has gone far ahead, not only of soda, but also of lime, becoming conspicuously the most soluble constituent. The remaining four constituents have relative solubilities not widely different from the normal, and if multiplied by five give soda 82, potash 10, silica 5, and sesquioxides 0.5. Such divergences from the average results are only what is to be expected, indicating, as they do, how local conditions control the action of drainage waters.

Headden has laid stress upon the high silica content of this water, in which respect it is remarkable, and not only is the content of silica high, but the relative solubility is also high, as compared with soda, potash and the sesquioxides. But, from the present point of view, the striking feature is not the silica content but the relatively great lime and magnesia content, implying high relative solubilities.

As in the case of soda in the sediments, but to a much more pronounced degree, low content of lime and magnesia is accompanied by high relative solubility, and it seems probable that this relation is a general one.

This relation is particularly suggestive in connection with the problem of ore deposits, where it is always so difficult to account for the concentration, into workable bodies, of minute quantities of disseminated metals. If the 0.74 per cent of lime and 0.07 per cent of magnesia can, by the differential solvent power of drainage waters, be concentrated to 31.12 per cent and 7.22 per cent, respectively, of the abundant oxides in the water, it is safe to assume that the much less abundant metals of rocks may undergo an analogous and, perhaps, even greater, concentration, by underground waters, either meteoric or magmatic. Perhaps this relation becomes more apparent if the relative solubilities of lime and magnesia are multiplied by five, as the others were to bring them up to the normal numbers. In this case the solubility of lime is 500 and that of magnesia is 1,222.

Of course, in the ore deposit problem, it is of vital importance to know what compounds of the metals are involved, but, in spite of the absence of such knowledge, it seems fair to infer that the minute quantities of metals that have sometimes been determined in rocks of mining districts have, because of their small quantities, higher relative solubilities than the other constituents of the rocks and thus take the first step, and perhaps a long one, toward their final concentration, when they go into solution in ground waters. The same doubtless applies to the rarer gangue materials as well.

One further special case may be added, particularly because it affords positive data as a basis of calculation, which were lacking in all the preceding cases. Reference is made to Headden's[1] experiments upon the solution of feldspar in carbonated water.

The powdered feldspar was treated with successive portions of distilled water for 48 hours, agitation being effected by a current of air containing a little carbon dioxide. Nearly 35 gallons of water were used, evaporated to dryness, and the residue analyzed. The results appear in column XXIII, the composition of the feldspar in XXIV, and the relative solubilities in columns XXV and XXVI.

	XXIII Feldspar Solution	XXIV Feldspar	XXV Solubilities	XXVI Solubilities (CaO = 100)
CaO.........	14.43	0.314	45.95	100.0
Na_2O.........	7.39	2.728	2.70	5.9
MgO.........	1.08	0.029	37.24	80.8
K_2O.........	15.45	11.592	1.33	2.9
SiO_2.........	57.41	65.760	0.87	1.9
R_2O_3.........	4.24	19.291	0.22	0.5

The agreement with the Cache à la Poudre figure is not as close as might be expected, the magnesia here occupying second place instead of first.

The relative solution concentration of magnesia, is less pronounced, for if all the figures be multiplied by five, while it gives high results for potassa, silica, and sesquioxides, the magnesia becomes only 404 as compared with 1,222. Still, the abnormally high relative solubility for constituents in small quantity is again illustrated. On the other hand, potassa shows no reduction of relative solubility as compared with soda, silica and sesquioxides, in spite of its high percentage in the feldspar, while soda, present in normal quantity, is conspicuously low in relative solubility.

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[1] *Op. cit.*, p. 181.

The wide divergences from mean relative solubilities shown by this experiment are to be accounted for on two grounds. In the first place, the conditions of the laboratory only roughly reproduced those of nature; while, in the second place, the feldspar varies rather widely from the mean composition of the rocks. The former fact may account for the relatively high solubility of potash, in spite of its large amount in the feldspar, and the low figure for soda, while the latter is doubtless responsible for the high figures for lime and magnesia.

It would be interesting to see what results would be yielded by similar experiments upon rocks representing the average surface, crystalline areas, etc., and the writer hopes that such experiments may be carried out in future. Meanwhile, the foregoing figures are presented not because they are regarded as important in themselves but rather as suggesting a promising line of investigation.

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